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This is a Capstone undergraduate student project that focused on introducing transient plasma ignition (TPI) into a small combustion engine (2 hp Fuji Imvac BF-34EI), seeking to demonstrate improved operating efficiency. The project was directed towards involving undergraduate students in the aerospace-oriented research activity. For this project, because the Department of Defense has identified the need for increased mission capability of future Unmanned Aerial Systems, including increased payload, range, and loiter time, it was deemed advisable to direct the undergraduate students work towards achieving these goals by modifying the engine ignition and combustion using TPI. TPI, involving short, intense, low-energy electrical pulses (typically 10-50 nanoseconds), has been shown to effectively improve engine performance for a wide range of combustion-driven engines relative to conventional thermal ignition, and earlier considerations suggested its potential for smaller engine applications.

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University of Southern California

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Transient Plasma Ignition for Small Internal Combustion Engines

FA9550-10-1-0554

Martin Gundersen / Paul Ronney

Abstract

This is a Capstone undergraduate student project that focused on introducing transient plasma ignition (TPI) into a small combustion engine (2 hp Fuji Imvac BF-34EI), seeking to demonstrate improved operating efficiency. The project was directed towards involving undergraduate students in the aerospace-oriented research activity. For this project, because the Department of Defense has identified the need for increased mission capability of future Unmanned Aerial Systems, including increased payload, range, and loiter time, it was deemed advisable to direct the undergraduate students work towards achieving these goals by modifying the engine ignition and combustion using TPI. TPI, involving short, intense, low-energy electrical pulses (typically 10-50 nanoseconds), has been shown to effectively improve engine performance for a wide range of combustion-driven engines relative to conventional thermal ignition, and earlier considerations suggested its potential for smaller engine applications. TPI is an attractive technology for the ignition of small internal combustion engines such as those used in unmanned applications because of engine data showing significant reductions in ignition delay, ignition of leaner fuel-air mixtures, lower specific fuel consumption, and faster burn rates. Successful results were achieved, and although preliminary, nevertheless demonstrated improved operating parameters, and potential for significantly impacting Air Force goals of improved engine performance on several levels, while employing basic research results of AFOSR-oriented research. The results included 25% increase in RPM with the same fuel consumption, indications of improved efficiency, and more consistent burn. In addition, miniaturized pulsed power conditioning, based on results from an AFOSR project in nanosecond pulsed power, was introduced that would be appropriate for development for airborne vehicles.

Introduction

The Fuji engine that is used for this work is installed on a lab bench, and is currently operational. A Windows PC with Labview and a National Instruments data acquisition card has been installed in the lab for use with this project. A dynamometer has been designed, built, and installed. It uses an automotive alternator with the field winding current varied to adjust the engine load. The alternator power output is sunk into electrical heating coils.

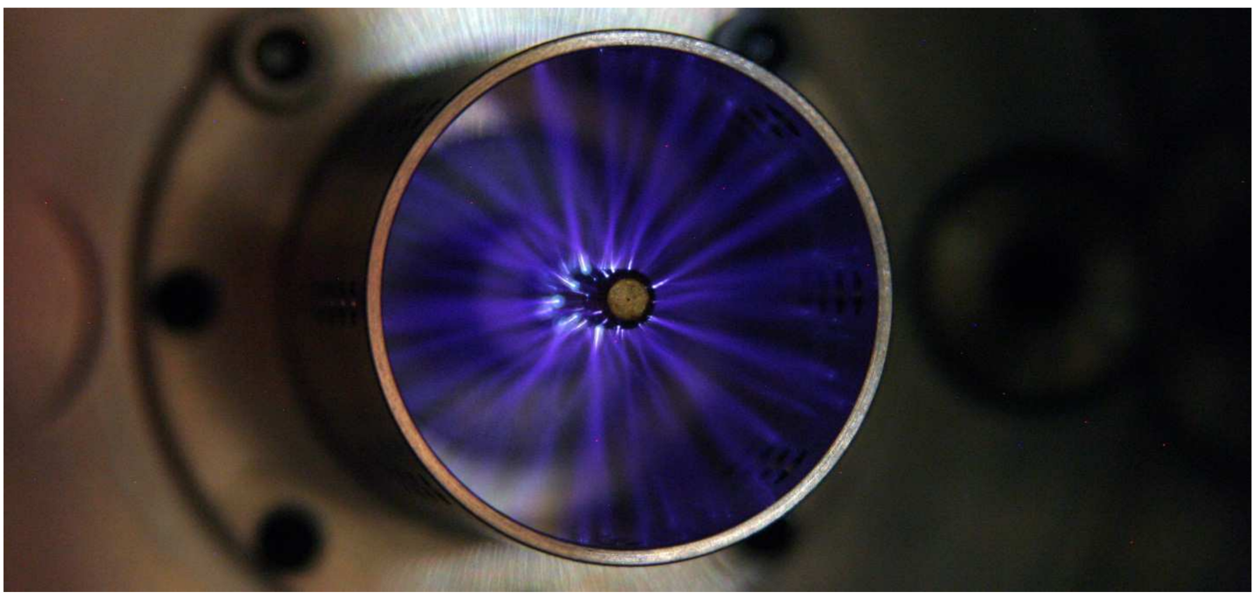
A force transducer mounted a known distance from the centerline of the engine is used to determine the engine torque. We have a 2000 g scale that is used as a load cell. A piezoelectric cylinder pressure transducer is used to measure cylinder pressure. The transducer has been installed in the engine.

The pulse generator to produce transient plasma ignition (TPI) for this experiment has been built. This device can operate up to 100 Hz, which is enough for a 4-stroke engine with a maximum RPM of 11,000. A TPI electrode compatible with the Fuji engine was designed and manufactured, and is ready for use. A shaft encoder will be used to determine crank angle; from this and the known geometry of the engine, the cylinder volume is easily calculated. From the pressure vs. time and volume vs. time, pressure-volume plots will be generated and work per cycle computed.

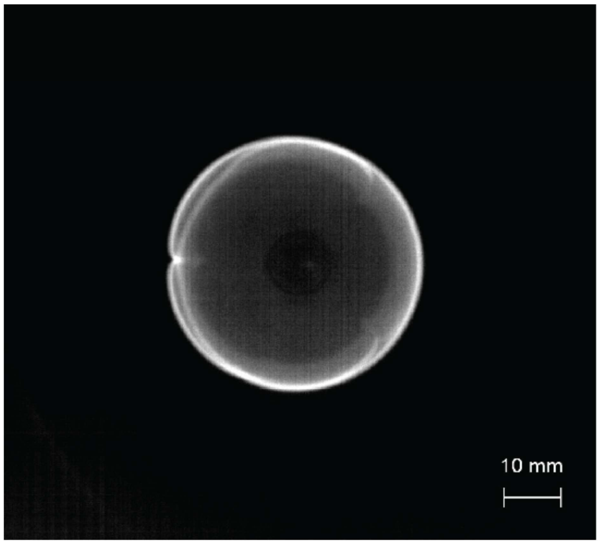
Background

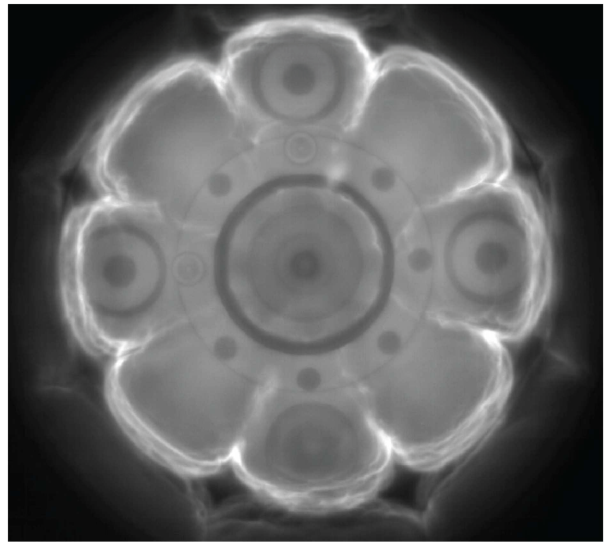
The DoD has identified the need for increased mission capability of future Unmanned Aerial Systems (UAS), including increased payload, range, and loiter time. Transient plasma ignition (TPI), involving short, intense, low-energy electrical pulses (typically 10-50 ns), has been shown to effectively improve engine performance for a wide range of combustion-driven engines relative to conventional thermal ignition [1-3]. TPI is an attractive technology for the ignition of small internal combustion engines such as those used in UAS because of engine data showing significant reductions in ignition delay, ignition of leaner fuel-air mixtures, lower specific fuel consumption, and faster burn rates. Here we describe research into development and optimization of TPI implementation in a single-cylinder 2 hp Fuji Imvac BF-34EI internal combustion engine.

Transient Plasma Ignition



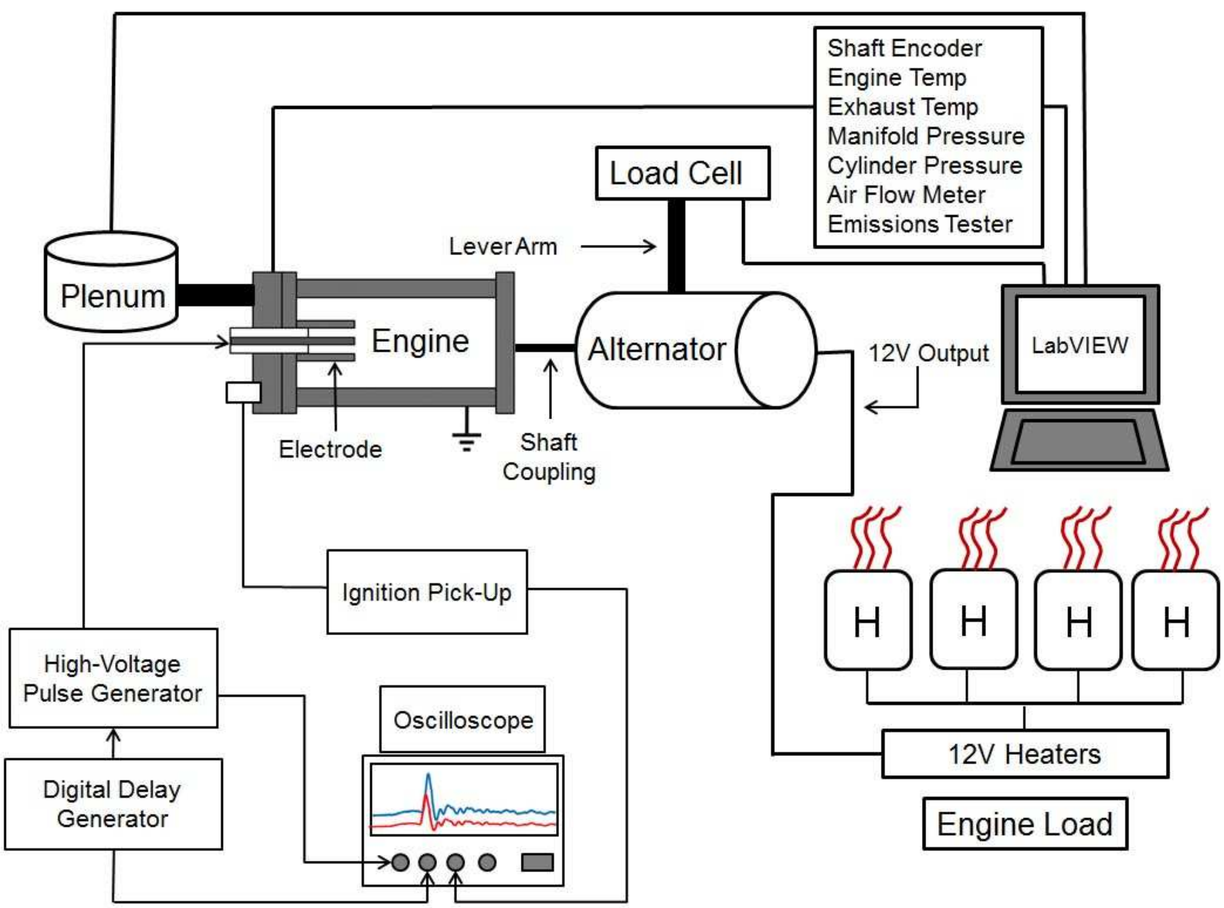
A single non-thermal transient plasma discharge in air favorably alters pre-combustion chemistry and physics. Shown here are streamers generated by a 54 ns, 61 kV pulse across a 15 mm gap [4]. Production of active particles in streamer channels through electron impact dissociation, excitation, and ionization of atoms and molecules significantly impact chain branching reactions, reducing ignition delay times and allowing for more complete combustion.



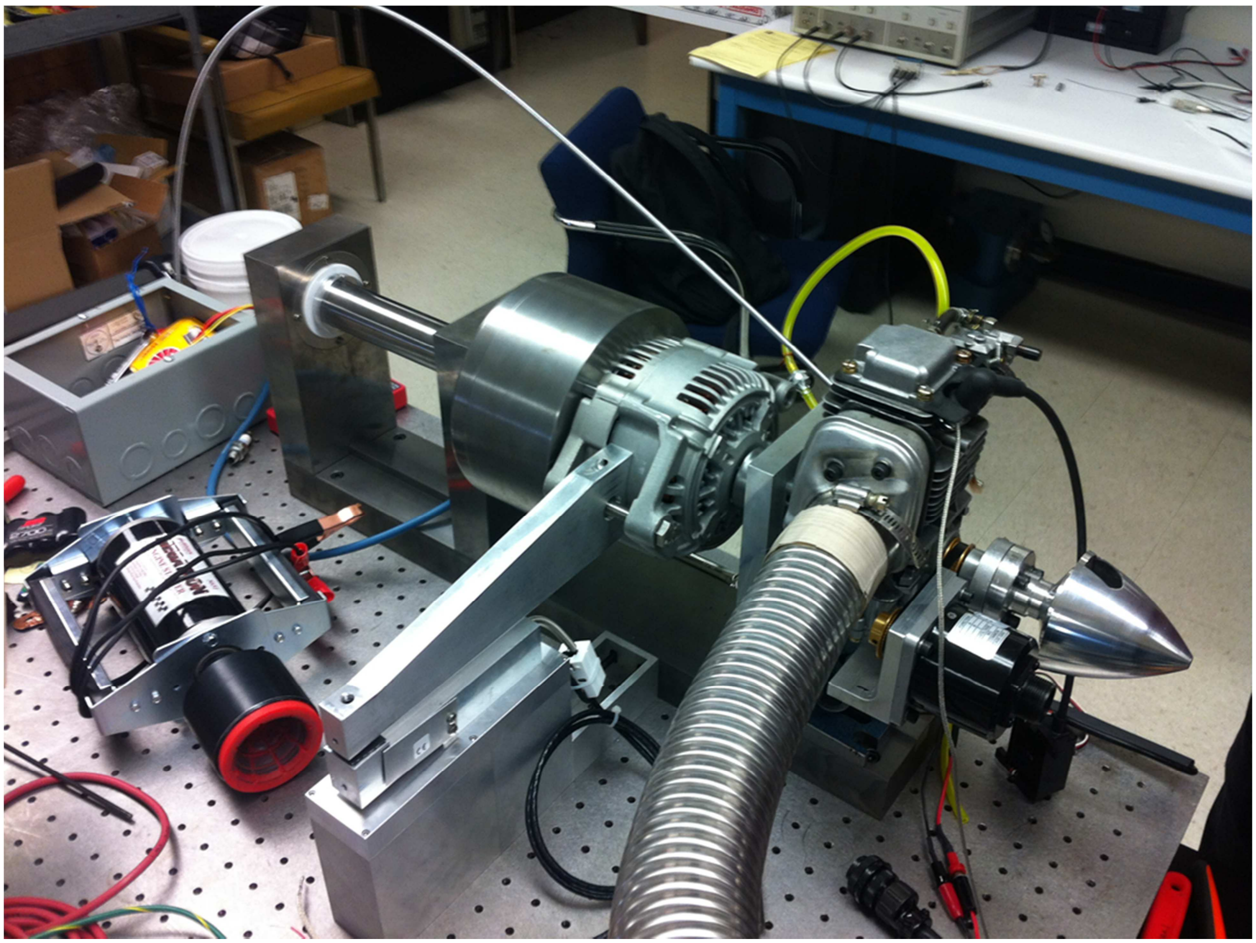


Photos of flame development in ethylene-air, 7 ms after discharge. Left: Spark ignition using a standard 105 mJ, 10 µs, 15 kV spark ignition system and a spark plug; Right: Transient plasma ignition using a 365 mJ, 54 ns, 56 kV pulse with a 15 mm gap [5].

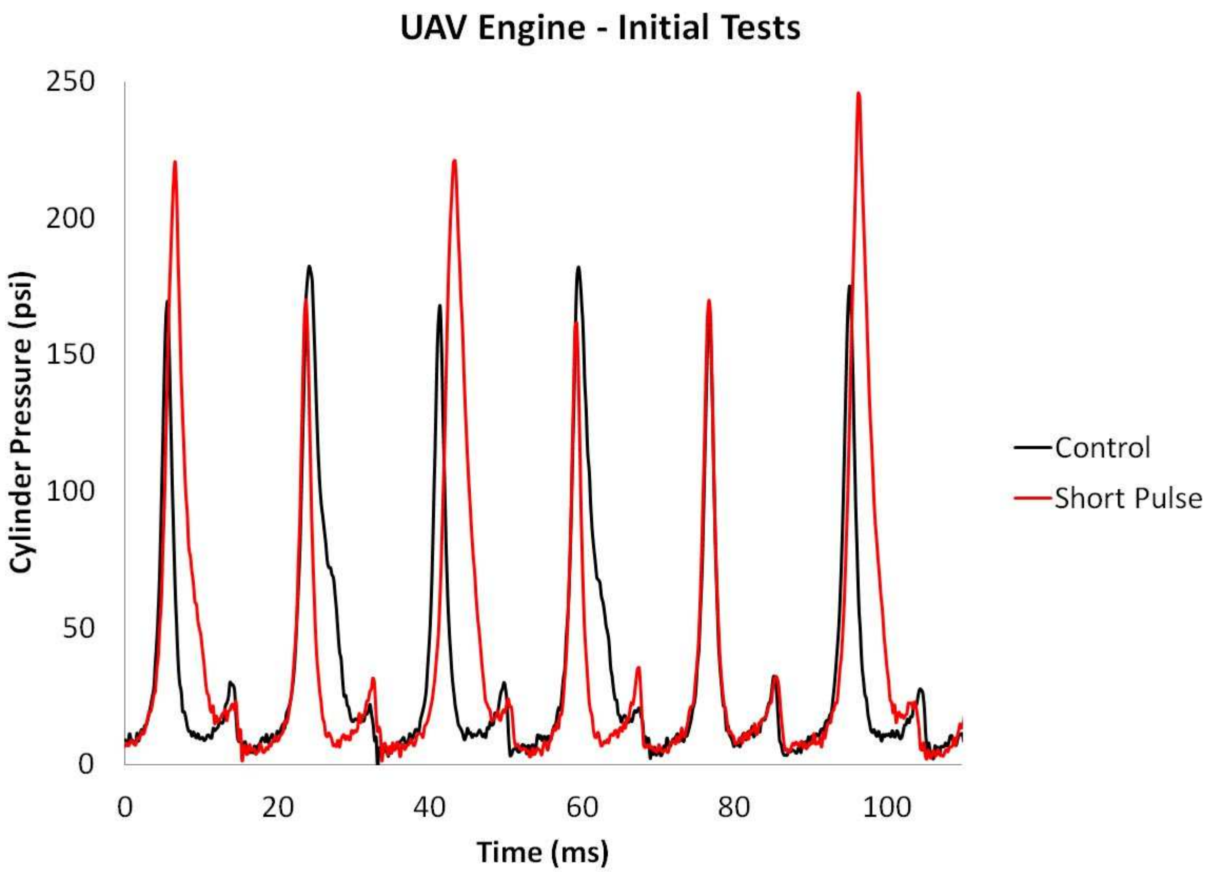
Experimental Setup



- Custom dynamometer with automobile alternator and heaters under construction
- Necessary engine parameters are logged using a LabVIEW virtual instrument
- A custom made plenum is used to prevent pulsing in the intake manifold and to stabilize the airflow measurements
- TPI system delivers a 50 ns, 25 kV, 50 mJ pulse to a non-resistive spark plug with coaxial electrode
- TPI delivered with the same timing as spark ignition (SI) based on magnetic pickup on the crankshaft



Results



Experiments performed in a 1-cyl gasoline engine, delivering one 50 ns pulse-per-cycle. Based on previous results with plasma enhanced combustion we except, greater than 10% improvement in combustion efficiency.

- Demonstrated TPI on small internal combustion engine in the USC lab
- Compared to SI, TPI results in 25% increase in RPM with the same fuel consumption
- Indicates improved efficiency
- TPI resulted in more consistent burn than SI
- Experiments will be performed once the dynamometer is operational

Future Work

After demonstrating faster burning rates and improved fuel efficiency with TPI, attention will be turned to engine design. The faster burn rates produced by TPI may be used in conjunction with intake port and combustion chambers intentionally shaped to provide reduced turbulence levels and thus reduce thermal losses while still obtaining rapid burn rates. Moreover, the reduced cooling system load means that smaller cooling systems can be used, thus reducing aerodynamic drag. This double benefit (increased efficiency and reduced drag) is potentially enabling technology for long-distance small engines having large combustion chamber surface area to volume ratios. Piston and cylinder head design, intake manifold flow straighteners, and ignition timing and air-fuel ratios will be explored in future work.

Summary

Using transient plasma in a single-cylinder gasoline engine, a 25% increase in RPM was demonstrated under the same operating conditions when compared to traditional spark ignition. A custom dynamometer is being constructed so that heat release and combustion efficiency can be measured.

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